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# EXPERIMENTAL STUDY OF DROPLET BIOFILTER PACKED WITH GREEN SPHAGNUM TO CLEAN AIR FROM VOLATILE ORGANIC COMPOUNDS

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**Abstract**. Volatile organic compound pollution is one of the problems of outdoor and indoor environment air quality. In order to maintain good air quality, air cleaning technologies are being engaged. One of the recent biological air treatment technology is biofiltration. It is a promising treatment of air from volatile organic compounds (VOCs).
Experimental research of droplet biofilter for cleaning VOCs was carried out. Biofilter load of green sphagnum was used with the aim to clean three different concentrations of pollutant toluene. Measurements of biofiltration processes were recorded after 20 and 40 days. The aim of this experimental research is to estimate biofilter efficiency using green sphagnum as a load material.

**Keywords:** volatile organic compounds (VOCs), environment, pollution, biofilter, biofiltration processes, air cleaning, toluene, experimental research, efficiency.

## Introduction

Volatile organic compounds include a variety of chemicals that are emitted by a wide array of products. The main sources of volatile organic compounds that could be found in households are organic chemical products that are ingredients in: paints, paint strippers, solvents, wood preservatives, aerosol sprays, cleansers and disinfectants, moth repellents and air fresheners, hobby supplies, pesticides, building materials, furnishings, office equipment, graphics and craft materials. As volatile organic compounds are used in household chemical products, they are used in the manufacturing and in production processes as: solvent thinners, degreasers, cleaners, lubricants, and liquid fuels.

VOC pollution comes from the anthropogenic and biogenic sources. On a worldwide basis, an emission of VOCs from biogenic sources (mainly vegetation) dominates (Atkinson, Arey 2003) (Table 1). Biogenic sources of VOCs are produced by plants. This process takes place when a plant is growing, developing, reproducing, forming self-defense and interacting with plant communities and insects. From the environmental side of view VOCs are organic odours produced in various industries as emissions of gases from certain solids and liquids. As for harmful substances, VOCs contain carbon which could be part of carbon monoxide, carbon dioxide, carbonic acid and other pollutants that participate in atmospheric photochemical reactions.

When there are large amounts of contaminant air emissions of VOCs in the presence of sunlight smog may form. As it can be seen in Figure 1, pollutant ozone increase in Europe is directly connected to VOCs and the amount of sunlight in the countries. Smog is harmful to human health and the surrounding ecosystems. To control harmful effects of VOCs, they should be treated using special control systems.

Table 1. Some of the common VOCs (Khan, Ghoshal 2000)

| Serial number | Volatile organic compounds |
|---|---|
| 1 | Acetaldehyde |
| 2 | Acetone |
| 3 | Benzene |
| 4 | Carbon tetrachloride |
| 5 | Ethyl acetate |
| 6 | Ethylene glycol |
| 7 | Formaldehyde |
| 8 | Heptane |
| 9 | Hexane |
| 10 | Isopropyl alcohol |

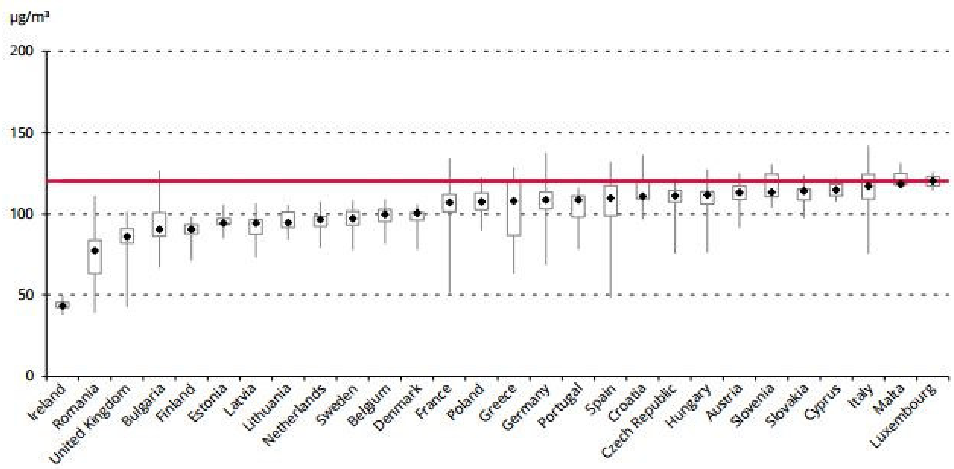


Fig. 1. $O_3$ concentrations in relation to the target value in 2014 in the EU-28 (*Source*: EEA 2016)

Alteration of this relationship by anthropogenically driven changes to the environment, including global climate change, may perturb these interactions and may lead to adverse and hard-to-predict consequences for the Earth system (Laothawornkitkul *et al.* 2009; Aplinkos apsaugos agentūra 2011; Arulneyam, Swaminathan 2005).

To avoid toxic and health threatening compounds in environmental and indoor air, different contamination treatment technologies are developed.

Various types of technologies have been created in an attempt to find the best treatment of air contaminated with volatile organic compounds. Two types of VOC controlling techniques can be distinguished: recovery and destruction. Some techniques are better in cleaning efficiency but require high maintenance, or are costly. There is only one technique that is both non-hazardous and does not require high initial investment – bio-filtration. So from environmental and economic view it is the best technique to use for VOC control (Baltrėnas *et al.* 2004; European Environmental Agency 2016; Kim *et al.* 2000).

## Methodology

Biofiltration is one of the most novel air pollution control technologies. Its mechanism of action is based on microorganisms that remove environmentally undesirable compounds during the biodegradation process.

Biofiltration uses microorganisms fixed to a porous medium to break down pollutants present in an air stream. The microorganisms grow in a biofilm on the surface of medium particles. The filter bed-medium consists of relatively inert substances (compost, peat, etc.) which ensure large surface attachment areas and additional nutrient supply. As the air passes through the bed, the contaminants in the air phase sorb into the biofilm and onto the filter medium, where they are biodegraded (Devinny *et al.* 1999). This technology is mainly used for the treatment of VOCs or inorganic air toxins. In general biological removal methods as biofiltration are used for soluble and low molecular weight VOCs: methanol, ethanol, aldehydes, acetates, ketones, and some aromatic hydrocarbons that are easily biodegradable (Leson, Winer 1991). A biofilter for control of air pollutants consists of one or more beds of biologically active material, primarily mixtures of compost, peat or soil. Filter beds are typically 1 meter in height. Contaminated off-gas is vented from the emitting source through the filter. Given sufficient resistance time, the air contaminants will diffuse into a wet, biologically-active layer (i.e. biofilm) which surrounds the filter particles. Aerobic degradation of the target pollutants will occur in the biofilm if microorganisms, mainly bacteria, are present that can metabolize them. End products from the complete biodegradation of air contaminants are $CO_2$ water, and microbial biomass. The oxidation of reduced sulfur compounds and chlorinated organic compounds also generates inorganic acids (Leson, Winer 1991; Operation and maintenance manual 2005). For the experimental research the droplet biofilter created in Vilnius Gediminas Technical University was used (see Fig. 2). This biological air cleaning technological device was filled with the green sphagnum load collected from the natural environment, and was fractionated and mixed with the peat moss.

The test stand is made from the biofilter frame that is the body of the device. The main characteristics of the stand are: 0.14 m of the diameter, 1.0 m of the height. The biofilter is connected with the circular water reservoir, pollutant supply chamber, the fan and rubber connecting tubes. In the biofilter there are 5 sections, every section is 10 cm height and 14 cm in diameter. Section layers are separated from each other with the metal grid. Polluted air

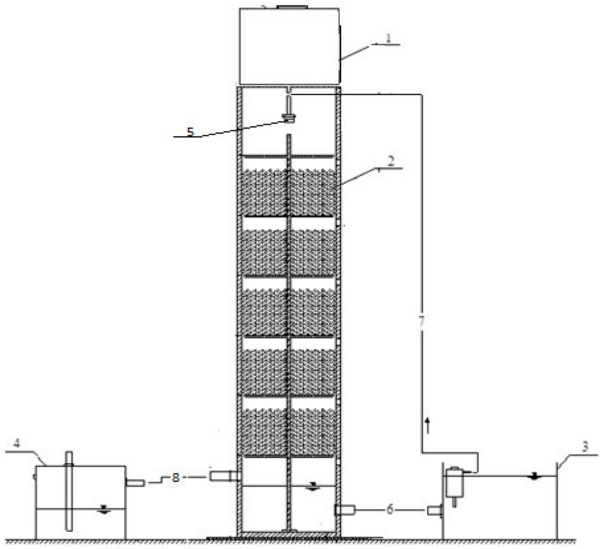


Fig. 2. Construction of a biofilter. Here: 1 – the fan for air traction; 2 – the load; 3 – circular water reservoir; 4 – pollutants supply to chamber; 5 – the water jet; 6, 7, 8 – rubber connecting tubes (Zagorskis, Spiečiūtė 2011)

will be passed through all the sections of the biofilter. The whole body of droplet biofilter stand was made from plastic.

Load of biofilter consisted of peat. Peat is a plant that grows in swamps and is highly capable of absorbing water and holding it in the porous parts of the plant structure. Porosity characteristics of the plant can affect the water flow in the lower layer of the biolfilter, which changes the conditions needed for the microorganisms to create the right environment to absorb and degrade the polluted air. The single most important operating parameter for this load media is the bed moisture content. The optimal value range of humidity needs to be between 50% and 60% for peat beds. If the bed becomes dry, the medium will repel water because of its hydrophobicity. So to preserve the humidity, load was irrigated every second day.

A fan is important for the air flow management in the biofilter. After every section there are special holes for the measurement of the air flow, pollution concentration and other parameters. These holes are sealed with the removable rubber plugs.

When the circular water reservoir fills with water and other materials, it is pumped to the top of the biofilter part where the injector sprays the water onto the top of the sphagnum load evenly. Sprayed water drops connect with the load and through the metal grids connecting the layers of sections go to the lower sections of the biofilter. In this manner all the layers are being activated in 20 days and the biological film is produced.

When the film in the biofilter is equivalent in all five sections the water with the pollutant solution is being poured to get the desired concentration of the pollutant – toluene steams. As it was mentioned before, the air system is managed with the fan. Then the air with the steams of the pollutant is supplied by vertical air flow through all the biofilter sections. In the load the first thing that happens – microorganisms absorb the pollutants that go through with the air flow, and then later they undergo biodegradation in the water phase. The air flow and the concentrations of the pollutants were measured after every section – in total five sections.

For the concentration measurement the American equipment MiniRAE 2000 was used. This device is used as a photo-ionization detector. The main advantages: lightweight and compact, dependable and accurate, user friendly, data logging capabilities. This device gives the real time measurements of gas concentrations in ppm. A wide spectrum of VOCs can be determined using this device (RAE Systems- MiniRAE 2000 2016).

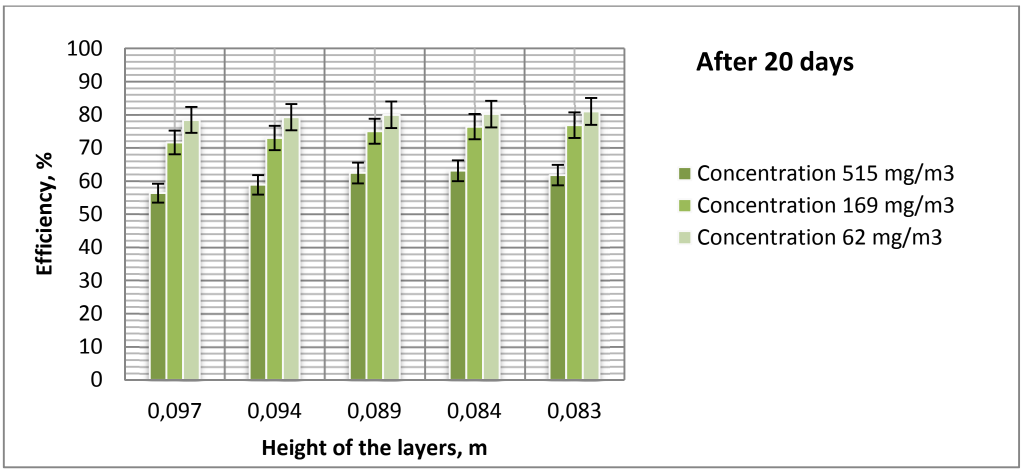


Fig. 3. Result of biofiltration efficiency air cleaning process after 20 days toluene contaminant initiation to biofilter

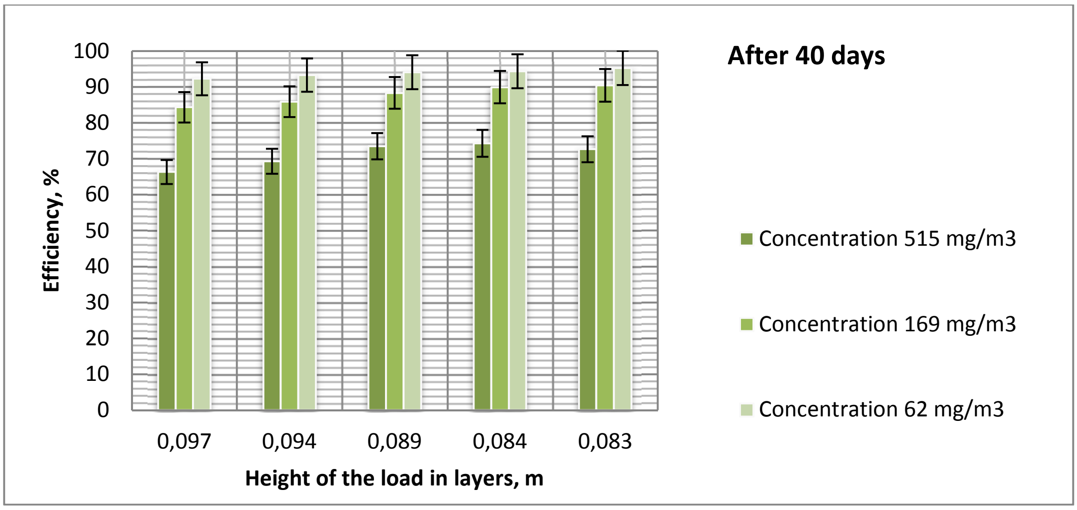


Fig. 4. Results of biofiltration efficiency in air cleaning process after 40 days toluene contaminant initiation to biofilter

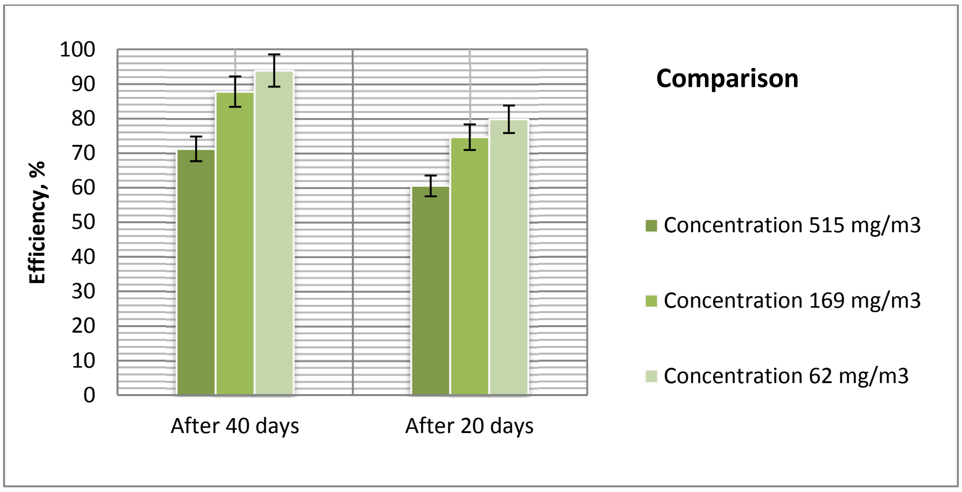


Fig. 5. Comparison of biofiltration average efficiency values in air cleaning process after 20 and 40 days of toluene contaminant initiation

The fan of air traction that is constructed on the top of the biofilter (Fig. 2, point 1) has one air flow slot; the air is suctioned at a speed of 0.08 m/s. The accuracy of the device when the air flow is 0.04–0.12 m/s ranges at ±5%.

In summary, toluene was the pollutant analysed. Three different concentrations of toluene were passed through the 5 layers of biofilter load of green peat moss (lat. Sphagnum). Initial air flow speed in the biofilter – 0.08 m/s in the range of ±5%. Contaminant concentrations were 400, 603 and 805 mg/m$^3$ in the range of ±5%. After the toluene was placed in the biofilter, 20 days were given for the load to adapt and grow microorganisms. First measurements were made after 20 days in every layer using MiniRAE 2000, second measurements – after 40 days.

## Results and analysis

The first measurements of biofilter efficiency values were done *after 20 days* using the same contaminant toluene and dependency of three different contaminant concentration values in five layers of biofilter see (Fig. 3). The values of efficiency varied from 56.37 to 81.00% in the range of ±5%.

At 515 mg/m$^3$ concentration the highest efficiency was reached in the last layer (height of 0.083 m) of the biofilter – 61.77 %, range ±5%. The lowest efficiency reached in the first layer (height of 0.097 m) – 56.37%, range ±5%.

At 169 mg/m$^3$ concentration the efficiency of the biofilter varied between 76.89 and 71.68%, range ±5%. The highest efficiency level was reached in the last layer (height of 0.083 m) of the biofilter – 76.9%, range ±5%, and the lowest efficiency in the first layer (height of 0.097 m) – 71.68%, range ±5%.

Efficiency at 62 mg/m$^3$ concentration varied from the lowest in the first layer (height of 0.097 m) – 78.43%, range ±5% to highest in the last layer (height of 0.083 m) – 81.00%, range ±5%.

Comparison of results. Difference of efficiency between the first and the last layers in all concentrations after 20 days varied at about 2.57–5.20%, after 40 days – 3.02–6.12%. These results suggest that the amount of the layers in this experiment did not have significant influence on the chages in the efficiency of the biofilter.

In comparison of the efficiency in relation to the time passed (Fig. 5) it is seen that efficiency increased from the average of 79.79% in all layers range ± 5% to 93.87% in all layers, range ±5% at the lowest contaminant concentration of 62 mg/m$^3$.

At the concentration of 169 mg/m$^3$ the average efficiency values in the time period from 20 to 40 days increased from 74.62% in the range of ±5% to 87.78% in the range of ±5%.

At the concentration of 515 mg/m$^3$ the average efficiency values in the time period from 20 to 40 days increased from 60.53% in the range of ±5% to 71.21% in the range of ±5%.

The efficiency after 40 days at concentrations of 515 mg/m$^3$, 169 mg/m$^3$, 62 mg/m$^3$ was respectively 72.67%, 90.45% and 95.29%, range ±5%.

The changes in efficiency observed leads to the assumption that the main limitations to the efficiency of toluene cleaning with a biofilter lie in the amount of time it stays in different layers and the initial concentration of the contaminant (Shareefdeen, Singh 2005; Sorial *et al.* 1997; Strack 2008; Vaiškūnaitė 2004, 2008; Wani *et al.* 1997; Wani *et al.* 2008; Zagorskis, Milaknytė 2013; Zagorskis, Spiečiūtė 2011).

## Conclusions

1. The results obtained suggest that peat moss as a medium load of biofilter is capable of eliminating toluene contamination from the air stream after 40 days at the efficiency of up to 95.29%, range ±5%.
2. The results of biofiltration efficiency *after 40 days* of contaminant – toluene – initiation to the biofilter load in different biofilter layers in three different concentrations are given in Figure 4. The efficiency of the biofilter varied from 66.32% to 95.29%, range ±5%. The contaminant removal from the air stream depended on the height of the layer and the concentration value.
3. The highest efficiency at 515 mg/m$^3$ concentration was reached in the last layer (height of 0.083 m) of the biofilter – 66.32%, range ±5%. The lowest efficiency reached in the first layer (height of 0.097 m) – 71.21%, range ±5%.
4. At the 169 mg/m$^3$ concentration of contaminant, the efficiency of droplet biofilter varied between 84.33 and 90.45%, range ±5%. The highest efficiency level was reached in the last layer (height of 0.083 m) of the biofilter – 90.45%, range ±5%, the lowest efficiency was observed in the first layer (height of 0.097 m) – 84.33%, range ±5%.
5. At the 62 mg/m$^3$ concentration of toluene, the biofiltering efficiency varied from the lowest in the first layer (height of 0.097 m) – 92.27%, range ±5% to the highest in the last layer (height of 0.083 m) – 95.29%, range ±5%.

## References

Aplinkos apsaugos agentūra. 2011. *Lakūs organiniai junginiai* [online], [cited 15 January 2015]. Available from Internet: http://chemija.gamta.lt/cms/index?rubricId=8cd1f017-e3b0-4663-836e-979d1ba2cbe5

Arulneyam, D.; Swaminathan, T. 2005. Biodegradation of mixture of VOC's in a biofilter, *Journal of Environmental Science* 16(1): 30–33.

Atkinson, R.; Arey, J. 2003. Atmospheric degradation of volatile organic compounds, *Chemical Reviews* 103(12): 4605–4638. https://doi.org/10.1021/cr0206420

Baltrėnas, P.; Zigmontienė, A.; Vaiškūnaitė, R. 2004. *Oro valymo technologijos:* monografija. Vilnius: Technika. 207 p.

Devinny, J. S., *et al.* 1999. *Biofiltration for air pollution control*. Boca Raton (Fla.): Lewis Publishers. 299 p.

European Environmental Agency. 2016. *Air Quality in Europe. EEA Report. No. 28/2016.* ISSN 1977-8449. 88 p.

Khan, F. I.; Ghosal, A. K. 2000. Removal of volatile organic compounds from polluted air, *Journal of Loss Prevention in the Process Industries* 13(2000): 527–545. https://doi.org/10.1016/S0950-4230(00)00007-3

Kim, N. J.; Hirai, M.; Shoda, M. 2000. Comparison of organic and inorganic packing materials in the removal of ammonia gas in biofilters, *Journal of Hazardous Materials* B72 2000: 77–90. https://doi.org/10.1016/S0304-3894(99)00160-0

Laothawornkitkul, J.; Taylor, J.; Hewitt, C. N. 2009. Biogenic volatile organic compounds in the Earth system, New Phytologist 184(1): 276. https://doi.org/10.1111/j.1469-8137.2009.02859.x

Leson, G.; Winer, A. M. 1991. Biofiltration: an innovative air pollution control technology for VOC emissions, *Journal of the Air & Waste Management Association* 41(8): 1045–1054. https://doi.org/10.1080/10473289.1991.10466898

Operation and maintenance manual [online]. 2005 [cited 15 May 2016]. Available from Internet: http://www.raesystems.com/sites/default/files/content/resource/FeedsEnclosure-MiniRAE_2000_RevE_0.pdf

RAE Systems- MiniRAE 2000 [online]. 2016 [cited 15 May 2016]. Available from Internet: http://www.raegasdetection.com/index.cfm?fuseaction=product.display&product_ID=19

Shareefdeen, Z.; Singh, A. 2005. *Biotechnology for odor and air pollution control.* Germany: Springer. 370 p. https://doi.org/10.1007/b138434

Sorial, G. A.; Smith, F. L.; Suidan, M. T.; Biswas, P.; Brenner, R. C. 1997. Performance of peat biofilter: impact of the empty bed resistence time, temperature and toluene loading, *Journal of Hazardous Materials* 53(1997): 19–33. https://doi.org/10.1016/S0304-3894(96)01842-0

Strack, M. 2008. *Peatlands and climate change.* Finland: Publisher International Peat Society. 227 p.

Vaiškūnaitė, R. 2004. *Research on and application of the biofilter with activated pine bark charge for air purification.* Vilnius: Technika. 31 p.

Vaiškūnaitė, R. 2008. Mathematical modelling of Biofilter's temperature regimes, in *the 7th International Conference Environmental Engineering* 22–23 May 2008, Vilnius, Lithuania. Selected papers, 1: 433–441. ISBN 978-9955-28-263-1.

Wani, A. H.; Branion, R. M. R.; Lau, A. K. 2008. Biofiltration: a promising and cost-effective control technology for Odors, VOCs and air toxics*, Journal of Environmental Science and Health*. *Part A: Environmental Science and Engineering and Toxicology* 32(7): 2027–2055 [online], [cited 15 May 2016]]. Available from Internet: http://www.tandfonline.com/loi/lesa19

Wani, H.; Branion, R. M. R.; Lau, A. K. 1997. Biofiltration: a promising and cost-effective control technology for odors, VOCs and air toxics*, Journal of Environmental Science and Health* A32(7): 2027–2055. ISSN: 1077-1204.

Zagorskis, A.; Milaknytė, A. 2013. Lavsano taikymo oro biofiltracijos procese eksperimentiniai tyrimai, *Science – future of Lithuania* 5(4): 376–381. ISSN 2029-2341 print / ISSN 2029-2252.

Zagorskis, A.; Spiečiūtė, R. 2011. Lašelinio biofiltro aerodinaminio pasipriešinimo tyrimai, *Science – future of Lithuania* 3(5): 64–69. ISSN 2029-2341 print / ISSN 2029-2252.

## LĄŠELINIO BIOFILTRO SU ŽALIŲJŲ KIMINŲ ĮKROVA EKSPERIMENTINIS TYRIMAS SIEKIANT IŠVALYTI ORĄ NUO LAKIŲJŲ ORGANINIŲ JUNGINIŲ

E. Petrauskaitė, R. Vaiškūnaitė

Santrauka

Lakieji organiniai junginiai yra oro taršos problema, atsirandanti tiek aplinkos ore, tiek vidaus patalpose. Siekiant užtikrinti gerą oro kokybę naudojamos oro valymo technologijos. Viena iš neseniai naudojamų technologijų yra biofiltracija. Tai daug žadanti oro valymo nuo lakiųjų organinių junginių (LOJ), technologija. Siekiant išvalyti tolueno teršalus naudojant lašelinį biofiltrą buvo atlikti eksperimentiniai tyrimai. Trims skirtingoms teršalo koncentracijoms išvalyti nuo lakiuoju organiniu junginiu toluenu užteršto oro biofiltro įkrovai buvo naudojami žalieji kiminai. Matavimai buvo atliekami po 20 ir 40 dienų. Šio eksperimentinio tyrimo tikslas buvo sužinoti, kokį efektyvumą gali pasiekti žaliaisiais kiminais įkrautas lašelinis biofiltras.

**Reikšminiai žodžiai:** lakieji organiniai junginiai (LOJ), aplinka, užterštumas, biofiltras, biofiltracijos procesai, oro valymas, toluenas, eksperimentinis tyrimas, efektyvumas.